Title: **Hotter Than Hot - Boiling Point Elevation in Non-Electrolyte and Electrolyte Solutions**

Brief Overview:

Colligative properties of a solution are properties that depend only on the number, and not the identity, of the solute particles. Boiling point elevation is such a property. A nonvolatile solute elevates the boiling point of the solvent in which it is dissolved. The boiling point elevation due to a specific solute is directly proportional to the molal concentration of the solution. Data is collected using the CBL with a temperature probe to record the boiling temperature of various concentrations of a given solution. Boiling point elevation at varying concentrations is then graphed and analyzed using the TI-82/TI-83 calculator. Separate electrolyte and non-electrolyte solutions are analyzed and compared using regression techniques.

Links to NCTM 2000 Standards:

- **Mathematics as Problem Solving, Reasoning and Proof, Communication, Connections, and Representation**
  These five process standards are threads that integrate throughout the unit, although they may not be specifically addressed in the unit. They emphasize the need to help students develop the processes that are the major means for doing mathematics, thinking about mathematics, understanding mathematics, and communicating mathematics.

- **Patterns, Functions, and Algebra**
  Students will write an algebraic equation that describes the variation of boiling point elevation with concentration for a given solute and compare slopes of resulting curves for different solutes.

- **Measurement**
  Students will gather temperature data in Fahrenheit then convert the data to Celsius. Regression equations formed will be stated in the context of the data used to create them. Students will incorporate a variety of techniques to obtain the required temperature data to include using CBL's to record temperature of a heated solution, gather a set of data over time and then calculate an average

- **Data Analysis, and Statistics**
  Boiling point temperatures will be obtained for a variety of solutions over a range of concentrations. These data will then be used to fit a linear regression model. Students will be required to comment on resulting linear model as to how well it fits or departs from the data. They will use the resulting models to make inferences as to the boiling points of solutions not taken. Students also will be asked to comment on sampling as well as non-sampling errors, which may be in the data sets.

Links to Virginia High School Mathematics Core Learning Units

- **A.5**
  The student will analyze a given set of data for the existence of a pattern, represent the pattern algebraically and graphically, and if possible determine whether ort not the relation is a function.

- **A.17**
  The student will, given a set of data points, write an equation for the line of best fit, using the median fit method, and use the equation to make predictions.

- **A.18**
  The student will compare multiple one-variable data sets, using statistical techniques that include measurement of central tendency, range, stem and leaf plots, and box-and-whisker graphs.

- **PS.4**
  The student will analyze scatter plots to identify and describe the relationship between two variables using shape; strength of relationship; clusters; positive and negative or no association; outlier and influential points. Appropriate technology will be used to generate scatter plots and to identify outliers and influential points.

- **PS.5**
  The student will find and interpret linear correlation, use the method of least square regression to model the linear relationship between two variables and use the residual plots to assess linearity. Appropriate technology will be used to compute correlation coefficients and residual plots.

- **PS.8**
  The student will describe the methods of data collection in a census, sample survey, experiment, and observational study and identify the appropriate method for a given problem setting.

Links to National Science Education Standards:

- **Science As Inquiry**
  Students will use a laboratory process to demonstrate an understanding of scientific inquiry.

- **Physical Science**
  Students will understand the difference between ionic and molecular compounds, the difference in the dissolving process of these compounds, and the effect of concentration on boiling point elevation of a nonvolatile solute. (Ionic/molecular structure, colligative properties, dissolution reaction)

- **Science and Technology**
  Students will understand the link between science and technology by using the CBL/TI calculator system to collect and analyze data.

Links to Virginia High School Science Core Learning Units:

- **CH.1**
  The student will investigate and understand that experiments in which variables are measured, analyzed, and evaluated, produce observations and verifiable data. Key concepts include: designated laboratory techniques; safe use of chemicals and equipment; proper response to emergency situations; manipulation of multiple variables with repeated trials; accurate recording, organizing, and analysis of data through repeated trials; mathematical and procedural error analysis, and mathematical analysis.

- **CH.4**
  The student will investigate and understand that quantities in a chemical reaction are based on molar relationships. Key concepts include solution concentrations, specifically molality.

- **CH.5**
  The student will investigate and understand that kinetic theory and forces of attraction between particles explain the phases of matter. Key concepts: solutions and colligative properties.

Grade/Level:

Grades 10/11; Algebra 2, Chemistry, Probability & Statistics, AP Statistics

Duration/Length

Three 50 minute periods

Prerequisite Knowledge:

Students should have working knowledge of the following skills:

- Preparing solutions of known molal concentration
- Use of the boiling point elevation equation
- Predicting the van't Hoff Factor "i" for specific solutes
- Graphing and identifying linear functions
- Entering data in the statistical lists on the TI-82/83
- Graphing a scatter plot
- Performing a regression to fit the data
- Graphing a regression curve by importing into the "Y=" list of the TI-82/83
- Accessing a program stored in the TI82/83

- Linking the CBL, TI82/83 and temperature probe
- Proper understanding and use of appropriate chemical terms

Objectives:

Students will:

- work cooperatively in teams.
- describe the relationship among boiling point elevation, concentration and the van't Hoff Factor "i".
- predict the slope of a linear equation for an electrolyte solution and a non-electrolyte solution.
- predict the relative boiling point elevation of a non-electrolyte and several electrolyte solutions.
- conduct an error analysis.

Materials/Resources/Printed Materials:

- CBL system with temperature probe
- TI82/83 calculator
- "CHILL" TI-82/83 program from Vernier
- 1 molal (1.0 m) solutions of Sodium Chloride (NaCl), Calcium Chloride ($CaCl_2$), Magnesium Chloride ($MgCl_2$) and Sucrose ($C_{12}H_{22}O_{11}$)
- 100 ml beakers (5), 250 ml beaker
- 100 ml graduated cylinder
- Hot plate/magnetic stirrer and stirring bar
- Safety goggles/apron
- Tongs/test tube clamp
- Glass stirring rod
- Distilled water
- Chem wipes
- Ring stand/iron ring/clamp/one hole stopper
- Balance
- 500 ml beakers (4)
- Spatula
- NaCl, $MgCl_2$, $CaCl_2$, $C_{12}H_{22}O_{11}$
- Weighing paper
- 250 ml graduated cylinder
- Micro pipets

Development/Procedures

1. The teacher will prepare the solutions as described below:

   a. 1.0 m NaCl: weigh out 58.45 g of NaCl and dissolve in 1000 ml of distilled water. Label container.
   b. 1.0 m $CaCl_2$: weigh out 100.98 g of $CaCl_2$ and dissolve in 1000 ml of distilled water. Label container.
   c. 1.0 m $MgCl_2$: weigh out 95.21g of $MgCl_2$ and dissolve in 1000 ml of distilled water. Label container.
   d. 1.0 m $C_{12}H_{22}O_{11}$ weigh out 342.12 g of $C_{12}H_{22}O_{11}$ and dissolve in 1000 ml of distilled water. Label container.

2. The teacher or student will:

   a. Load the "CHILL" program into your TI-82/83. Note: any program that will allow you to monitor the output of the temperature probe is useable.
   b. Connect the temperature probe, CBL and TI-82/83 as shown in the student lab worksheet.
   c. Follow the directions given in the student lab worksheet.

Assessment:

- The student worksheets will be collected and graded.
- A class discussion will follow the lab to assess student comprehension.
- When appropriate, students may be asked to reconfigure the experiment using new compounds of their choice.
- Students will be graded on demonstration of laboratory skills**.**

Extension/Follow Up:

- Repeat the experiment using KCl and compare the results to that of NaCl.
- Repeat the experiment using $CuCl_2$ and compare the results to that of $CaCl_2$.
- Repeat the experiment using $Al_2(SO_4)_3$ and predict the slope of the line.
- Repeat the experiment adding salt to boiling water. (Refer to Extension Notes for additional information.)

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Title: Hotter Than Hot – Boiling Point Elevation in Non-Electrolyte and Electrolyte Solutions

Pre Lab

The purpose of this laboratory activity is to measure the colligative property of boiling point elevation (ΔT_{bp}) as a function of molal concentration for several electrolyte and non-electrolyte solutions.

To prepare:

Determine the gram-molar mass of NaCl, $MgCl_2$, $CaCl_2$, (KCl-optional), $C_{12}H_{22}O_{11}$.

Dilute 1.0 m solutions of each salt to 0.5m, 0.25m, 0.125m, 0.0625m

Compare the experimental gram-molecular mass to their theoretical mass.

Background:

In laboratory work it is very common to work with moles to measure solution concentration. Molality (M - # moles of solute per liter of solution) is a common measure of concentration. However, there is a direct relationship between boiling point elevation (ΔT_{bp}) and molality (m - # moles of a solute per kilogram of solvent), a less common measure of concentration. You will study the relationship between boiling point elevation and molal concentration in this laboratory activity.

Colligative Properties:

When a solute (substance dissolved) is mixed with a solvent (substance that does the dissolving) a solution (homogeneous mixture) forms. A solution and its pure solvent may appear similar, however, some of their properties are different. For example, their boiling points will differ. Boiling points depend on the number of solute particles in solution. Sugar, a non-electrolyte, does not dissociate. It has polar ends that are attracted to the polar ends of the water molecule. When 1 mole of sugar dissolves, it produces only 1 mole of particles. Electrolytes such as salts do dissociate. NaCl dissociates into two ions Na^+ and Cl^- in water; $MgCl_2$ dissociates into three ions, one Mg^{+2} and two Cl^- in water. Properties that depend on the concentration of solute particles are colligative properties. In this experiment you will be observing the colligative property of boiling point elevation.

You can change the boiling point of the solvent (distilled water) by adding different amount of solute. This will cause the boiling point to rise. One mole of solute dissolved in one kg (1000 ml) of distilled water will raise the boiling point by 0.512^oC. This process results in a constant change in boiling point. The value 0.512^oC is the molar boiling point constant for water (K_{bp}). The constant can be used to calculate the change in boiling point of water solutions. You can predict the temperature change (ΔT_{bp}) before doing your experiment. The direct relationship between boiling point elevation and molal concentration is represented mathematically by the formula: $\Delta T_{bp} = iK_{bp}\,m$ (where i = van't Hoff factor).

The van't Hoff factor predicts the number of particles a solute will dissociate into.

Remember: $BP_{new} - BP_{original} = \Delta T_{bp}$ therefore $BP_{solution} = BP_{solvent} + \Delta T_{bp}$

Title: Hotter Than Hot – Boiling Point Elevation in Non-Electrolyte and Electrolyte Solutions

Pre Lab Questions: **Student Name:________________**

1. **Define the following : dissolve, solution, solute, solvent, molality, colligative properties, concentration**

2. **Determine the molar mass of: NaCl, $MgCl_2$, $CaCl_2$, $C_{12}H_{22}O_{11}$, KCl**

3. **How could 1 mole of solution in 1 kg of solvent change the boiling point of a solution by 0.5°C?**

4. **K_{bp} for water is what value?**

Title: Hotter Than Hot – Boiling Point Elevation in Non-Electrolyte and Electrolyte Solutions

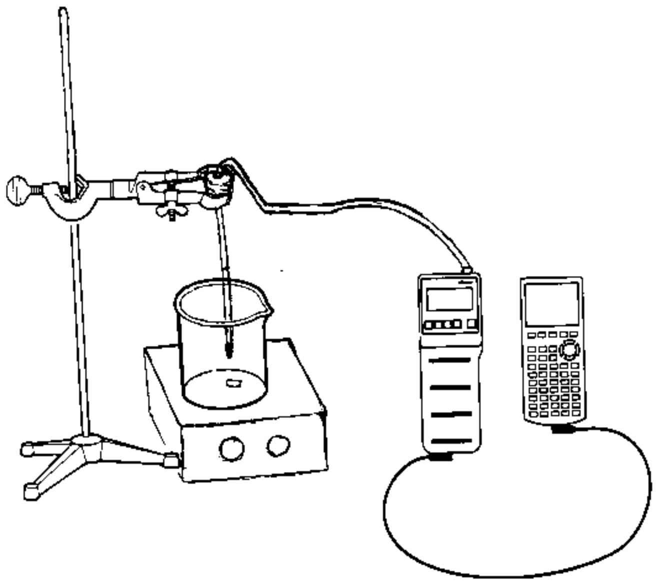
STUDENT LAB WORKSHEET STUDENT'S NAME____________

PART A

1. **Safety First!** Wear safety goggles and apron. Handle heated glassware carefully with tongs.

2. Students will work in groups of 2 or 3 and alternate roles of experimenter and recorder. Each group will collect data on one sample and share their results with other groups.

3. Set up your apparatus as shown in Figure 1 below.



NOTE: Do not let thermometer probe touch glass.

4. Get 200 ml of the solution assigned to your group by the instructor. Put 100 ml of this solution into a 100 ml beaker labeled 1.0 molal NaCl.

5. Take the second 100 ml of 1.0 m solution and dilute it with 100 ml of distilled water. Put 100 ml of this new solution into a 100 ml beaker labeled 0.5 molal NaCl.

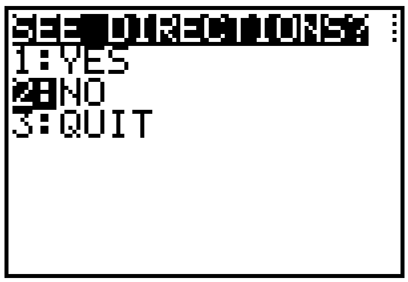
6. Take the second 100 ml of 0.5 m solution and dilute it with 100 ml of distilled water. Put 100 ml of this new solution into a 100 ml beaker labeled 0.25 molal NaCl.

7. Take the second 100 ml of 0.25 m solution and dilute it with 100 ml of distilled water. Put 100 ml of this new solution into a 100 ml beaker labeled 0.125 molal NaCl.

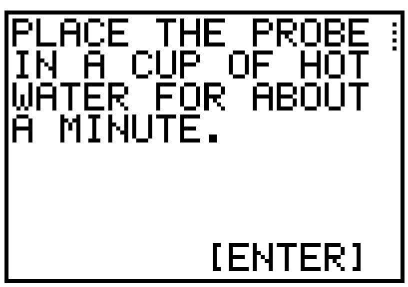
8. Take the second 100 ml of 0.125 m solution and dilute it with 100 ml of distilled water. Put 100 ml of this new solution into a 100 ml beaker labeled 0.0625 molal NaCl.

9. Place the 1.0 m beaker on a hot plate; place a magnetic stirrer bar in the beaker. Turn both the heater element and the stirrer on. Place the temperature probe about half way into the solution. Make sure the probe is not touching the glass and that it is not in the vortex created by the stirrer.

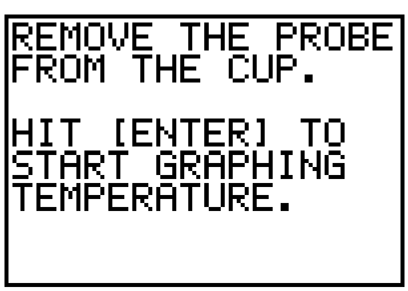
10. Once you begin the heating process press the mode key on the CBL so it begins to display the temperature of the solution. As the solution continues to heat begin to run the CHILL program on your calculator. However, **stop at screen shown below**:



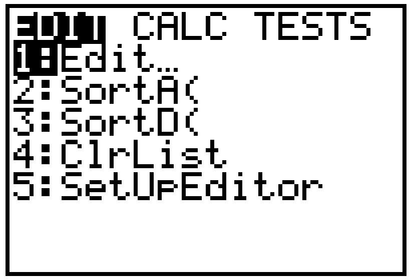
Carefully, watch the CBL readout. The solution will begin to boil as the temperature begins to reach 100 degrees Centigrade BUT watch the CBL readout until you see the same temperature being displayed. Once this happens FIRST- press the mode key on the CBL to return it to the CHILL program then…. SECOND - press the <enter> key on your calculator to get the screen shown below. THIRD - immediately press the <enter> key on your calculator again.



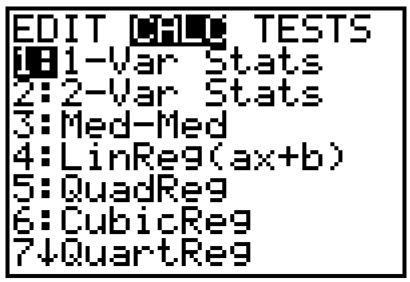
Now you get the screen shown below. But **DO NOT REMOVE THE PROBE!!!,** **Finally,** FOURTH - Immediately press the <enter> key again. Now you are sampling the temperature of the solution at the boiling point. The samples will be stored in List 2 (L_2) of your calculator



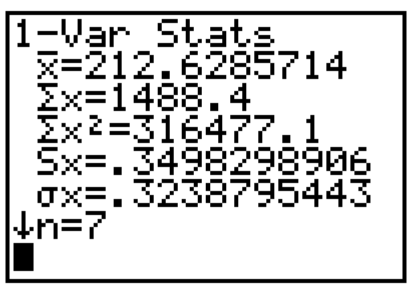
Watch the CBL display. When the CBL displays "DONE" on the left-hand side of the readout press the STAT key on your calculator which will bring up the following screen. Press the right arrow key to highlight "CALC" and press <enter>



Now this screen appears. Select 1-Var Stats



When the 1-Var Stats prompt appears on the home screen add L_2 after the prompt (second function 2) and press <enter>. What is now displayed on the calculator are the statistics (measures of central tendency and measures of dispersion of the boiling point temperature samples which were stored in L_2 by the CBL. The value you want to record on your worksheet is the value for x-bar which is shown 212.629 (rounded) in the example below.



11. Repeat steps 4 and 10 for all five solution concentrations.

12. Record the boiling point temperature for pure distilled water using the same procedures as in steps 4 to 10.

13. Using the following equation, calculate the boiling point elevation for each solution.

$$\Delta T_{bp} = iK_{bp}m$$

where i = van't Hoff Factor
K_{bp}= boiling point elevation constant for distilled water is 0.512 degrees centigrade/molal
m = molal concentration

14. Complete the above procedure for all solutions assigned to your group and get necessary data from other groups to complete Data Table A.

15. Use your data and calculate the line of best fit using the linear regression capability of your graphing calculator. Follow the example below for each of your data sets.

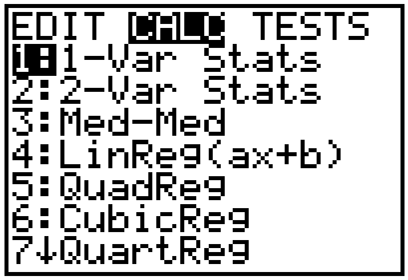
Solution: NaCl :

Concentration	Delta T ^{o}C
0.0625 m	0.399
0.125m	0.499
0.25m	0.904
0.5m	1.41
1.0m	2.838

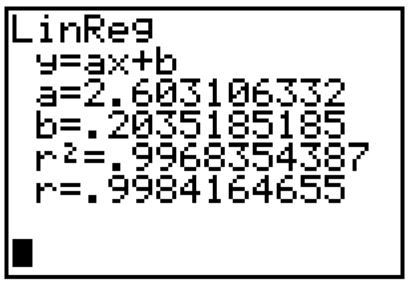
put the data in your calculator as follows then press your <STAT> key and choose <CALC> with the right arrow key

L1	L2
.0625	.399
.125	.499
.25	.904
.5	1.41
1.0	2.838

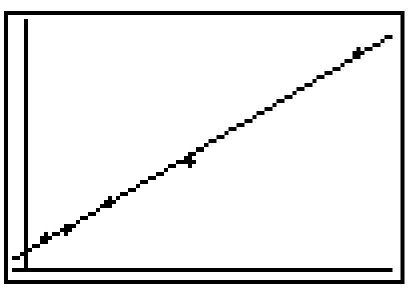
This window will appear. Choose choice 4. LinReg(ax+b). Press <enter>



When the expression LinReg(ax+b) appears on the home screen key in L_1, L_2 and press <enter>. This screen should appear:



To create the equation y=ax+b from this information do the following steps on your calculator: press <y=> and place the cursor at the end of \Y1= . next, press <VARS><5> use right arrow and tab over to <EQ> and choose RegEQ. Press <enter>. Your regression equation has now been placed in Y1 of the calculator. To graph the equation along with your data use the stat plot function of your calculator and graph L1, L1 and Y1at the same time. You should get the screen shown below:



Follow these procedures for each of your data sets. Record the regression equation for each solution on your worksheet.

Title: Hotter Than Hot – Boiling Point Elevation in No-Electrolyte and Electrolyte Solutions

STUDENT LAB WORKSHEET STUDENT'S NAME____________

DATA TABLE A

Identity	Molal concentration	Average boiling temperature ^{o}F	Boiling temperature ^{o}C	Change in boiling point
Distilled H_2O				
NaCl	1.0 m			
NaCl	0.5 m			
NaCl	0.25 m			
NaCl	0.125 m			
NaCl	0.0624 m			
$CaCl_2$	1.0 m			
$CaCl_2$	0.5 m			
$CaCl_2$	0.25 m			
$CaCl_2$	0.125 m			
$CaCl_2$	0.0624 m			
$MgCl_2$	1.0 m			
$MgCl_2$	0.5 m			
$MgCl_2$	0.25 m			
$MgCl_2$	0.125 m			
$MgCl_2$	0.0624 m			
$C_{12} H_{22} O_{11}$	1.0 m			
$C_{12} H_{22} O_{11}$	0.5 m			
$C_{12} H_{22} O_{11}$	0.25 m			
$C_{12} H_{22} O_{11}$	0.125 m			
$C_{12} H_{22} O_{11}$	0.0624 m			

Title: Hotter Than Hot – Boiling Point Elevation in Non-Electrolyte and Electrolyte Solutions

STUDENT LAB WORKSHEET STUDENT'S NAME____________

DISCUSSION QUESTIONS

1. Write the dissociation equation for:

   NaCl ____________________
   $CaCl_2$ ____________________
   $MgCl_2$____________________
   $C_{12}H_{22}O_{11}$ _________________

2. What is the number of particles produced by each formula unit when a sample of each solute in question 1is dissolved in water?

3. What is a colligative property?

4. Predict the relative boiling points of a 0.5 molal water solution of each of the solutes in question 1. Explain your reasoning.

5. Do the experimental results agree with those predicted in question 4? Discuss reasons for any deviations.

6. If the recorded boiling temperature of pure distilled water were inaccurate on the high side, how would that effect your results?

7. If, when you were making your 0.5 molal solution, you added 105 ml of distilled water instead of 100 ml, how would that effect your results?

8. Boiling point elevation (ΔT_{bp}) is directly proportional to molal concentration:

$$\Delta T_{bp} \sim m\ (i)$$

$$\Delta T_{bp} = iK_b m \text{ (Equation 2)}$$

where i = van't Hoff Factor
K_b = boiling point elevation constant for water (0.512^oC/molal)
m = molal concentration

Equation (2) is the equation for a straight line passing through the origin (y = mx). The slope of the resulting straight line is: i x K_b. Your results should produce a straight line. Determine the slope of the plot for each solution and calculate the experimental value of the van't Hoff Factor for each solute used.

Solute	Slope	i (Experimental)
NaCl		
$CaCl_2$		
$MgCl_2$		
$C_{12}H_{22}O_{11}$		

9. The theoretical van't Hoff Factor is determined by assuming complete dissociation of strong electrolytes in solution. In reality ion pairing takes place to some extent, particularly in more concentrated solutions.

   Predict the theoretical value of the van't Hoff Factor for each solute and determine the percent difference between this theoretical value and the experimental value you determined in Question 8.

Solute	i (Theoretical)	i (Experimental)	% Difference
NaCl			
$CaCl_2$			
$MgCl_2$			
$C_{12}H_{22}O_{11}$			

Title: Hotter Than Hot – Boiling Point Elevation in Non-electrolyte and Electrolyte Solutions

TEACHER RESOURCE/SAMPLE RESULTS

The authors completed this activity and collected the following data.

Solution: NaCl

Concentration	Delta T ^oC
0.0625 m	0.399
0.125m	0.499
0.25m	0.904
0.5m	1.41
1.0m	2.838

Solution: $MgCl_2$

Concentration	Delta T ^oC
0.0625m	1.416
0.125m	1.477
0.25m	1.699
0.5m	1.849
1.0m	3.127

Solution: $CaCl_2$

Concentration	Delta T ^oC
0.0625 m	0.410
0.125m	0.700
0.25m	1.471
0.5m	1.488
1.0m	2.560

Solution: $C_{12}H_{22}O_{11}$

Concentration	Delta T ^oC
0.0625m	Not Done
0.125m	0.010
0.25m	1.332
0.5m	1.810
1.0m	1.849

the Boiling Point of the water sample used to calculate the Delta T was 98.39 ^oC

Electrolyte (0.05 molal)	Predicted van't Hoff Factor "i"	Actual van't Hoff Factor "i"
NaCl	2.0	1.9
$MgCl_2$	3.0	2.7
$FeCl_3$	4.0	3.4
$MgSO_4$	2.0	1.3

Statistics Worksheet

This activity can be used as a data collection and analysis activity for any statistics class. It is recommended for students who had a course in chemistry; otherwise, they will have difficulty in explaining why observed data departs from theoretical/expected results.

Statistics students will be expected to collect the data in the same manner as the chemistry students. However, in order to expedite the data collection and reduce the time spent in the laboratory it is recommended that that the teacher prepare in advance the four to five different concentrations of solutions.

It is also recommended that the class be divided into groups of no more than 2 students so more than one group can do the same chemical solution in order to be able to compare results.

After the data has been collected using the same procedures as outlined for the chemistry students, scatter plots generated and appropriate regression equations have been obtained have the students present their findings and address the following issues:

> Is a linear regression model the most appropriate model for the inferences being made? If not, why not and what would be a more appropriate model?
>
> If there are differences between two or more groups who evaluated the same chemical at the same concentrations what factors can be used to account for the differences in recorded boiling points?
>
> Is there significant evidence of boiling point elevation as a function of increased concentration?
>
> Based upon the data collected, can the number of ionic particles in a given solution be correlated to the difference between the boiling point of pure water and the boiling points of the various solutions?
>
> Describe the slope of each regression equation in the context of the data used to generate the equation.
>
> During the course of the data collection activity what might have been the source of sampling as well as non-sampling errors? How could they have been reduced or eliminated all together?
>
> How well did the collected data compare to theoretical/predicted data?
>
> How do box-whisker plots of the data compare to each other?

Extension Notes

1. The salts added to water increase the boiling point and will make the water boil at a higher temperature. The water will be hotter at boiling. If this principle were applied to cooking, the food will cook faster at a higher temperature.

   Salt added to foods that are boiled, such as, spaghetti, rice, raw or frozen vegetables, hot dogs, hard boiled eggs, stir fry, etc. will shorten the cooking time. Stir-fry is usually cooked with soy sauce, which has a high sodium content and cools quickly. The adding of the sodium salt also enhances stir-fry.

   There is caution to adding salt to a recipe. Adding salt can make the foods taste more salty. Care must taken not to make foods taste too salty. Salt added to prepared mixes would change the taste and be undesirable for cooking foods that cook better at lower temperatures for a longer time, such as, breads, cakes, cookies, meats, and pies.

2. Salt is added to the street in winter to decrease the freezing temperature. If a pipe were frozen, a mole of salt added to water and boiled, then poured down the drain at night could help. This should be done at night so that the pipe will not thaw and then refreeze and expand and break. The mole of salt water will increase the water temperature and decrease the freezing temperature.

3. Use another salt, $AlCl_3$ in place of either $MgCl_2$ or $CaCl_2$. Both $MgCl_2$ and $CaCl_2$ dissociate into 3 ion parts, while $AlCl_3$ dissociates into 4 ion parts.